Grade 11: Waves and Sound

Cymatics Demonstration: Handout #1

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The Physics:

Cymatics is the study of wave phenomena, specifically in the form of controlled vibrations (i.e. Sound Waves) and their interactions with each other and the mediums they travel through, creating visible nodes and antinodes. This will be seen in the demonstration via the construction of various patterns on a Chladni Plate.

About the Geometry:

- Nodes and antinodes are the spaces where waves either perfectly destructively interfere with each other or perfectly constructively interfere with each other.
- In the case of nodes, two waves are 180 degrees (pi radians) out of phase with each other and have the same amplitude, leading them to cancel each other out and create a spot with zero total amplitude.
- On the other hand, in the case of antinodes where waves perfectly constructively interfere with each other. Two waves with the same amplitude and the same phase will reinforce each other creating a spot with double the amplitude.
- In our model of a Chladni Plate, as the waves travel throughout the plate and create nodes and antinodes, the salt that's on top of the plate will naturally travel from the antinodes to the nodes, from spots that have lots of vibrations to spots that have no vibrations traveling through them.

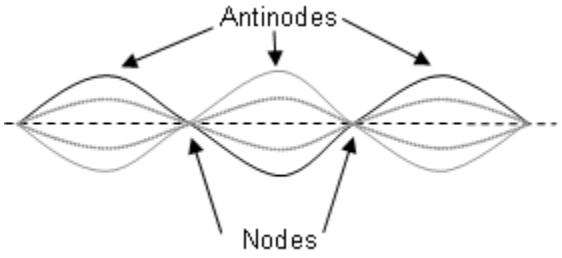

Figure 1: Depiction of nodes and antinodes on a waveform.

About the Variables of the medium:

- Depending on the medium, waves will travel through and interact in a great variety of ways, in the case of water, as the density, depth, viscosity of the water, shape and size would change the visual effects as well.

- Though, in the case of a simple Chladni Plate, much of these variables are taken out of the picture and allows us to hold the variables constant, instead solely focusing on just the frequency the plate is vibrating at.

Resonance:

As the vibrations travel through the medium (the plate) it will react due to its ‘resonant modes’, a wave that has a frequency matching the frequency of the medium's natural frequencies of vibration, creating standing waves. As we traverse the vibrational frequencies, we will hit a number of different standing waves of the medium, each one corresponding to their own geometrical symmetries.

The pattern formed by the Chladni plate is not the frequency itself, but rather the resonant mode of the medium that was created by that specific frequency. What we see on the plate isn't a specific sound that we’re hearing, but the resonant mode of a medium that is excited by that sound, thus creating a visual that is specifically created by a combination of all the different variables at play.

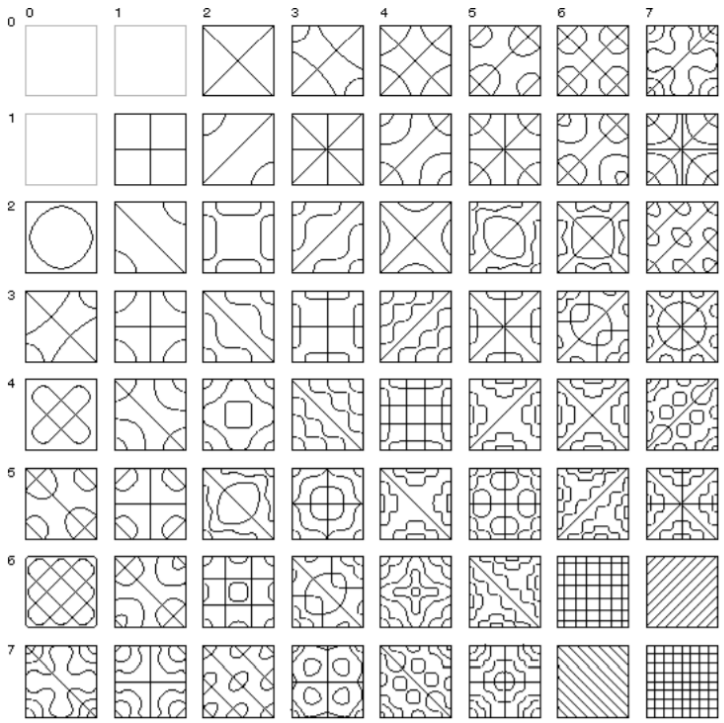

Figure 2: Chladni figures for a square steel plate (adapted from Waller 1961) demonstrates the fantastic variety of standing wave patterns that can arise from a simple resonating system. A square steel plate is clamped at its midpoint and sprinkled with sand. It is then set into vibration either by bowing with a violin bow, or by pressing dry ice against it. The resultant standing wave patterns are revealed by the sand that collects at the nodes of the oscillation where the vibration is minimal. (From [1])

Hypothesis:

We establish two hypotheses about the change we observe in the shapes of visualized sound. (from [2]).

$$v = \sqrt{\frac{\beta}{\rho}}$$ (where, v = Wave Velocity, β= Bulk Modulus, ρ= Density) (1)

$$v = \lambda f$$ (where, v = Wave Velocity, λ= Wavelength, f= Frequency) (2)

1. Relation between the type of board and the shape on the board (metal plate and the piezo sounder, in our model):

   According to (1), sounds that have the same frequency have different velocities because of the bulk modulus of their media. If the velocity varies, according to (2), the wavelength would change. This change indicates that the distance between two consecutive nodes would differ according to its material. The lines are formed by particles on the node, so the change of location of nodes would result in the change of the shape.

2. Relationship between the frequency of the corresponding sounds and the shape (geometry) on the plate:

   According to (2), the change of sound frequency would result in the change of wavelength. Because these changes result in the change in locations of the nodes and consequently the shape displayed on the plate will vary.

The Demonstration:

A common Physics demonstration utilizes a square metal plate (known as a Chladni plate), a speaker and salt. Salt (or sand) is sprinkled upon the plate in an irregular pattern. When a tone is generated by the speaker or by strumming the plate with the bow, the plate begins vibrating. The salt upon the plate begins vibrating and forms a pattern upon the plate.

All objects have a set of natural frequencies at which they vibrate; and each frequency is associated with a standing wave pattern. The pattern formed by the salt on the plate is the standing wave pattern associated with one of the natural frequencies of the Chladni plate. As the plate vibrates, the salt begins to vibrate and tumble about the plate until it reaches points along the plate that are not vibrating. Subsequently, the salt finally comes to rest along the nodal positions. Being unable to move, they become nodal points – points of no displacement. ([4])

Materials Needed:

- **Piezo Sounder**: that will be used for the generation of the vibrations that create the visual phenomena.

- **Metal Plate**: A metal plate that will rest on top of the piezo sounder, acting as the medium in the demonstration.

- **Signal Generator**: for powering the piezo sounder, it will allow us to run the sounder through ranges of frequencies needed for the demonstration.

- **Salt**: the visual representation of cymatics, it will be acted upon by the waves created in the medium.

- **Bowl**: to catch any loose salt that falls off the plate.

- **Stand**: to elevate the plate/piezo sounder/salt above the bowl, allowing for greater visibility and less interference from outside sources.

Constructing the Demonstration:

1. Place the bowl onto a solid surface, the stand in the centre of the bowl

2. Attach the piezo sounder to the top of the stand and secure the plate to it.

3. Hook up the piezo sounder to the signal generator and sprinkle a tiny amount of salt onto the top of the plate.

4. Done, the demonstration is set up. Keep extra salt around as after use some of it will have made it off of the place.

5. Before running the demonstration in front of an audience, if possible cycle through the frequencies yourself. Marking down the frequencies that will create standing waves in the medium being used as well as the entire set up in general.

Showing the Demonstration:

Start off by showing a mixed layer of salt on top of the plate, and explaining roughly what the set up entails. A piezo sounder with a metal plate on top, and asking what the students think will happen when the piezo sounder begins to vibrate the plate, doesn't explicitly say if they're wrong or right, letting the demonstration speak for itself instead.

Turn on the piezo sounder at the lower frequency that enacts a standing wave in the plate, discussing the results and whether their ideas of what would happen to salt was correct or incorrect. Next, ask the students what they think causes that specific pattern in the salt and what will happen if you change the frequency. Explaining the two hypotheses and asking which one they think is the real cause of the patterns.

After a brief discussion with the students, turn the signal generator back on at the original frequency before slowly increasing the frequency till you reach the next one that creates standing waves in the medium. Explaining that it is only at certain frequencies that the patterns are created, otherwise the salts will move around randomly and without a specific pattern. Returning to the two hypotheses mentioned earlier, explain that the specific patterns are actually created by two of them working in sync. That the specific frequencies create the standing waves in the plate and that when these standing waves occur then nodes and antinodes form, creating the patterns that we see. Briefly explaining each of the topics as well as the equations that go along with each of the hypotheses.

After the explanation, do one final demonstration of the Chladni plate by cycling through some more of the frequencies, and simply showing all the different patterns that can be formed by going to the different frequencies. Explaining the standing waves that are formed, and how they depend on the specific medium in question and its resonant modes. Covering any additional piece of physics information that is vital to the demonstration and the curriculum.

References:

1) *Lehar, S. (2003). Harmonic Resonance Theory: An alternative to the "Neuron Doctrine" paradigm of neural computation to address gestalt properties of perception. The Behavioral and Brain Sciences, 26(4), 15.*

2) *Oh, Y. J., & Kim, S. (2012). Experimental study of cymatics. International Journal of Engineering and Technology, 4(4), 434.*

3) *Jenny, H. (2001). Cymatics: a study of wave phenomena and vibration. Macromedia.*

4) *https://www.roelhollander.eu/en/tuning-frequency/cymatics/*

Cymatics Demonstration: Handout #2

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Questions:

1. In this demonstration, do you think the frequency of the vibration (of the generating sound waves) is the only factor that affects the shape (geometry) of the patterns we observed? If not, what other factors are contributing to the outcome? *(7 marks)*

2. Show a particular result capturing the nodes and antinodes on the pattern observed. *(3 marks)*

3. Do you think cymatics possess any physical meaning to its structure or is it just a mere projection of fascinating geometries as an art form? If yes, what do you think could be the real-world scientific applications of these observed patterns? *(4 marks)*

4. Give an example of cymatics in 3-dimensions. How do you expect them to behave in 3D? *(6 marks)*